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COTTON LINT YIELD ACCUMULATION RATE AND QUALITY DEVELOPMENT

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ABSTRACT

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Crop production management during the period of boll setting and maturation of cotton (*Gossypium hirsutum* L.) is critical in determining lint yield and quality. A field investigation conducted at Lubbock, Texas, during 1977—1980 included three cultivars to study the effect of temperature on factors that influence the rate of cotton yield accumulation and the development of lint quality parameters.

A linear regression of physiological days (heat units) explained 93% of the variation in prebloom period expressed in days. The number of physiological days needed to complete the prebloom period was negatively related to average daily temperature in a linear manner and included a significant cultivar effect.

The length of the boll setting period was determined by temperature and plant moisture stress. In the absence of plant water stress, 20—25 physiological days were needed to complete boll setting. The length of time to fully mature bolls was related to air temperature in a negative exponential manner (r^2 = 0.85) with little direct influence of plant water stress or effect of cultivars. Average boll weight of crop increments fluctuated, but the only trend across years was for the mean boll weight of the last two crop increments to be smaller than the average for the total crop. However, there was a direct correlation between the percentage of total bolls set and percentage of final yield.

Fiber micronaire was correlated with temperature in a positive linear manner. In the absence of significant plant water stress, temperature explained 80—90% of the micronaire values of individual cultivars compared with 60% when moisture stress conditions were included. An average crop boll temperature of 27°C appears adequate to achieve maximum development of fiber micronaire. Fiber strength also displayed a linear increase as boll period temperature increased, with coefficients of determination ranging from 0.60 to 0.77 among cultivars. Plant water stress significantly reduced micronaire values but had little effect on fiber strength. Fiber length was not affected by the range of environmental conditions during the four-year period of the study.

INTRODUCTION

Cotton crop quantity and quality is a composite of the characteristics of individual bolls. Due to the indeterminate fruiting habit of cotton, changing

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external environmental factors and internal plant nutritional status can result in significant differences among individual bolls produced in a field. It is also commonly recognized that differences in genetic potential exist among commercial cotton cultivars.

In the time-wise development of the boll, Schubert et al. (1973) found that fiber elongation ceased after 55% of the boll period was completed and fiber thickening began when 35% of the boll period had elapsed. Thus, both fiber elongation and thickening were occurring simultaneously during 20% of the boll period. In the same study, the maximum rate of lint weight increase occurred when 55—60% of the boll period was completed. Using field-grown cotton plants, Benedict et al. (1973) found that maximum incorporation of ^{14}C-assimilate into developing fiber occurred 23—40 days after anthesis. Rate of fiber dry weight increase was maximal prior to completing fiber elongation at 25—30 days after anthesis. A field study by Leffler (1976) showed that the dry weight of the boll wall reached final weight three weeks after bloom when seed and lint had reached only 40% of their final weight. In mature bolls, the boll wall accounted for about 21%, the seed for about 38%, and the lint for about 41% of the boll dry weight. The results of a study by Kohel and Benedict (1984) indicated a significant environmental effect on final dry matter partitioning among boll components. In a cool wet year wall, seed, and fiber dry weight were 22, 42, and 36%, respectively, compared with 23, 46, and 28% in a dry warm year.

The length of the boll period is related to temperature in a negative exponential manner (Mutsaers, 1976; Wanjura and Newton, 1981). Boll period variations among cultivars of 4—13% under field conditions have been reported (Morris, 1964; Yfoulis and Fasoulas, 1973). In a study using four cotton cultivars grown in the Canberra phytotron, Hesketh and Low (1968) found that seedcotton weight per boll reached a maximum at an average temperature of about 27°C.

The cotton production area in the Southern Great Plains is characterized by highly variable growing environments in which the growing season is usually shortened because of low temperatures. Low temperatures often occur during the latter portion of boll setting and during the peak period of boll maturation. These low temperatures reduce lint yield and fiber quality. Thus, a fundamental understanding of the relationship of temperature to boll development and the overall state of crop maturity is essential to evaluate crop condition on a real time basis. Estimation of crop condition is especially important when adverse weather events occur.

The purpose of this study was to investigate the influence of environmental factors on boll development parameters that influence rate of cotton yield accumulation and the effect of temperature on fiber quality parameters.

MATERIAL AND METHODS

Field studies of boll development were conducted at the Texas Agricultural Experiment Station, Lubbock, TX, during the four-year period 1977—

TABLE 1

Monthly rainfall and irrigations during four growing seasons, 1977—1980, Lubbock, TX

Year	Rainfall (mm)					
	May	June	July	August	September	Total
1977[a]	55	52	34	84	9	234
1978[b]	89	61	2	6	79	237
1979[c]	111	101	48	103	5	368
1980[d]	72	38	8	48	100	266

[a]Applied a 50 mm irrigation (solid basis) in alternate furrows on 25 July.
[b]Applied 90 and 50 mm irrigations (solid basis) in alternate furrows on 21 July and 8 August.
[c]No in-season irrigation.
[d]Applied 75 mm irrigations (solid basis) in alternate furrows on 7, 16, and 28 July; and 13 and 28 August.

1980. The cultivars 'Paymaster 303' and 'Paymaster 909' were tested in four years and 'Acala 3080' during the last three years.

Cotton was grown in rows spaced 1 m apart and normal production practices were used. A preplant herbicide was applied broadcast and a preplant furrow irrigation was used to ensure adequate planting moisture. Postplanting irrigation supplemented rainfall; 0, 1, 2, or 5 irrigations were applied (Table 1). Rainfall and temperature data were obtained from a weather station located 0.4 km from the experimental site.

The procedure for monitoring boll development consisted of observing all bolls that formed in two 3-m lengths of row in each variety. Coded paper tags were attached to new blooms each day and the total number of blooms initiated was recorded. This procedure continued for the duration of the crop blooming cycle. The bolls were considered to be mature and harvested when the carpels cracked from light squeezing pressure applied by grasping the boll between the fingers. The length of the boll period was computed from the coded tags attached to each mature boll. After harvesting, the bolls were oven dried and weights of individual bolls were determined. The total number of bolls from each row plot was subdivided into ten equal crop increments according to date of bloom. Each crop increment was ginned and fiber properties were measured by the Texas Tech Textile Research Laboratory.

Data analysis consisted of computing the length of the boll setting period, which is the time between the dates when the first and last permanent bolls were initiated expressed in days. Permanent bolls are those which remain on the plant until maturity. The relationship of temperature to the boll period of each cultivar was analyzed by computing the average boll period and average temperature for each crop increment. Average boll size of the crop increments was compared. The relationship of fiber micronaire and strength to temperature and to location within the boll setting cycle was examined.

In analysis, relating the temperature effects on boll period and on fiber quality parameters, average daily temperature (TAVG) was computed as the sum of maximum temperature (TMAX) and minimum temperature (TMIN) divided by two. For specifying certain stages of crop development accumulated chronological and heat units since the stand establishment date were used. Heat units were calculated after the procedure of McKinion et al. (1975) and called "p-days". A p-day is calculated as (TAVG−12)/14. Thus, a day on which TAVG was 26 resulted in a p-day value of 1.0. Values of TAVG below 12°C are ignored.

RESULTS AND DISCUSSION

Crop field development

Environmental conditions

Monthly rainfall amounts for each of the years and the quantity of supplemental irrigation are summarized in Table 1. Planting dates, stand establishment, date of first bloom, and plant population data are shown in Table 2.

Rainfall and irrigation in 1977 were adequate to prevent a soil moisture limitation on rate of boll setting. July and August rainfall in 1978 was very low, and the irrigation on July 21 was applied after plants had experienced some water stress. Rainfall in 1979 was plentiful from May through August and very low in September. Plants were probably not deep-rooted because of plentiful soil moisture, and the dry period in late August and September caused significant plant moisture stress beginning in early September. Rainfall in 1980 was low during June and July; however, sufficient supplemental irrigation was applied to prevent damaging levels of plant moisture stress.

Monthly maximum and minimum temperatures (Table 3) show that 1980 was the warmest of the four years during June, July, and August. It is during July and August that bolls are formed, with the concurrent initiation of lint and seed production. September temperatures in 1977 were the most favorable of the four-year period for lint development during that month.

Prebloom period

The length of time between stand establishment and first bloom (prebloom) was linearly related to heat units measured in p-days (r^2 = 0.93), as shown in Fig. 1. That the relationship was common among years was somewhat surprising, since seedlings in 1979 were subjected to cool weather and leaf damage from blowing sand to the extent that seedlings with damaged leaves were common three weeks after the initial date of stand establishment.

The total of heat units needed to complete the prebloom phase was inversely related to average temperature and varied among cultivars (Fig. 2).

TABLE 2

Agronomic summary for three cultivars during four growing seasons, 1977—1980, Lubbock, TX

Cultivar	Planting date	Stand establishment date[a]	First bloom date	Population (plants/ha)
1977				
Paymaster 303	May 20	May 26	July 16	130 800
Paymaster 909	May 20	May 26	July 16	130 800
1978				
Paymaster 303	May 10	May 17	July 9	134 000
Paymaster 909	May 10	May 17	July 12	114 600
Acala 3080	May 10	May 18	July 15	134 000
1979				
Paymaster 303	May 9	May 17	July 23	142 100
Paymaster 909	May 9	May 17	July 23	116 200
Acala 3080	May 9	May 17	July 27	98 500
1980				
Paymaster 303	May 13	May 26	July 8	114 600
Paymaster 909	May 13	May 26	July 9	108 200
Acala 3080	May 13	May 27	July 11	98 500

[a]Stand establishment date was defined as the day when 50% of the final number of plants had emerged.

TABLE 3

Monthly maximum and minimum temperatures during four growing seasons, 1977—1980, Lubbock, TX

Year	Average temperatures (°C)									
	May		June		July		August		September	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1977	27.6	14.8	32.7	18.3	32.8	19.4	31.9	19.3	31.9	16.4
1978	27.7	13.6	32.3	18.3	35.3	20.6	31.9	17.3	27.4	16.6
1979	26.3	12.6	30.4	16.4	32.5	19.7	29.8	17.4	29.4	13.2
1980	26.4	12.0	35.1	20.2	36.4	20.7	32.9	20.1	28.3	16.5

The linear correlation coefficient between average temperature and p-days for all cultivars combined was −0.81 compared with values of −0.99, −0.96, and −0.99 for Paymaster 303, Paymaster 909, and Acala 3080, respectively. The correlations of Paymaster 303 and Acala 3080 were statistically signifi-

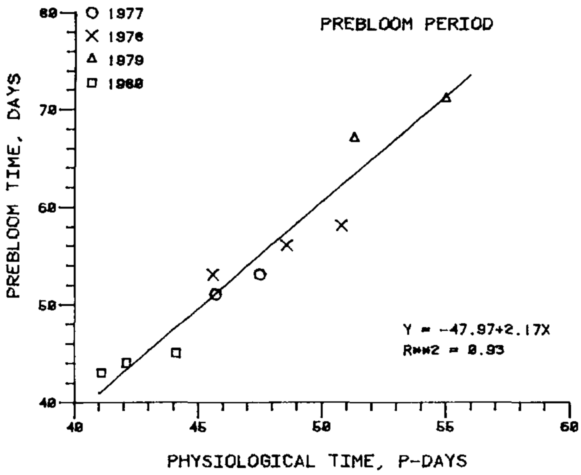

Fig. 1. Dependence of prebloom time on physiological time.

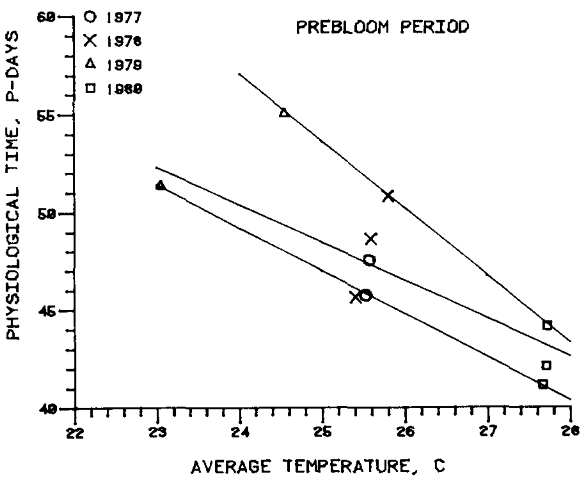

Fig. 2. Dependence of the physiological time during the prebloom period on average daily air temperature and cultivars. The top curve is Acala 3080, middle curve is Paymaster 909, and the bottom line is Paymaster 303.

cant at the 0.05 probability level. For the period 1978—1980 the range in physiological time to complete the prebloom period as a percentage of the average of the three cultivars was 10.8, 7.0, and 7.0, respectively. Plant water stress in 1979 and 1980 was minimal because of adequate rainfall or sufficient irrigation. Consequently, the 7% value for the range among cultivars may be an estimate of the genetic influence on variation in prebloom time and 2.8 percentage points (10.8—7.0) an estimate of the contribution of plant water stress in 1978. Unfortunately, measurements of plant water status were not made.

Rate of boll setting

The rate at which the crop was set, expressed as a percentage of total number of permanent bolls, was strongly related within years to cumulative heat units expressed in p-days (Table 4). Among years, plant water stress influenced the rate of crop set as shown by the slope coefficients (b-values). Rate of crop setting during the four years was compared by testing for homogeneity of b-values and found to be significantly fastest and slowest in 1979 and 1978, respectively, with no difference in rates between 1977 and 1980. Apparently plants had a minimal level of water stress during fruit set in 1977 and 1979, resulting in high rates of crop boll setting with little difference between cultivars. Supplemental irrigations in 1978 and 1980 were apparently insufficient to prevent plant water stress and the rate of boll setting was reduced, with greater differences among cultivars than in 1977 and 1979.

TABLE 4

Relationship between cumulative percentage of total bolls (Y) and cumulative physiological days since first bloom (X) for all cultivars combined

Year	Linear regression coefficients		r^2	S.E.b
	a	b		
1977	10.17	4.03	0.93	0.26
1978	4.29	2.26	0.94	0.11
1979	−13.27	5.02	0.98	0.12
1980	2.61	3.21	0.84	0.26

In spite of plant moisture stress during boll setting in 1978 and to some degree in 1980, the linear effect of cumulative p-days accounted for at least 84% of the accumulation rate of bolls (r^2 values, Table 4). Averaged across cultivars, one physiological day represented 4.0, 2.3, 5.0, and 3.2% of the accumulation of the crop of bolls in 1977, 1978, 1979, and 1980, respectively. There were statistically significant differences in 1978 through 1980 between the cultivars having the smallest and largest regression coefficients, indicating a genetic effect on rate of boll setting in response to p-days. When plant water stress was minimal during boll setting, as in 1977 and 1979, 20–25 p-days were required to complete boll setting.

Boll period

The total number of bolls set in each cultivar was subdivided into ten equal crop increments and the average temperature for each increment was computed. The relationship between boll period and average temperature for each crop increment of each cultivar is described by an exponential relationship, as shown by the example of Acala 3080 in Fig. 3. The boll periods of

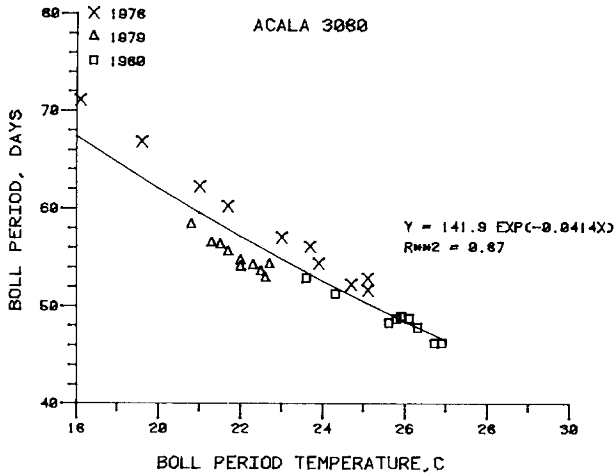

Fig. 3. Negative exponential relationship between boll period length and boll period air temperature for Acala 3080.

Acala 3080 in 1978 were longer than for the other two cultivars; otherwise, cultivar boll periods were very similar. Mutsaers (1976) analyzed boll period data reported by several investigators and found that an exponential equation described the relationship between boll period and average temperature. The boll period equation for the combined data of all cultivars and years, based on 110 observations, is BP = 137 EXP ($-0.0405T$), $r^2 = 0.85$.

In general, the equation suggested by Mutsaers (1976) predicts longer boll periods than the equation for our combined data. The Mutsaers equation is based on data collected in the field, greenhouse, and controlled environment chambers while our data were collected in the field, sometimes from plants subjected to water stress. While water stress per se probably does not materially affect boll period, water stressed plants have higher temperatures than do nonstressed plants. We measured canopy temperatures in water stressed cotton plants in July 1980 that averaged 1.7°C higher than in nonstressed plants (data not reported).

Boll size

Average boll size varied considerably among years for the same cultivar but the environmental effect of different years generally influenced the cultivars in a similar manner (Table 5). The coefficient of variability of boll size within a cultivar for the same year ranged from 9 to 16%. In general, the variability in boll size among crop increments was highest in 1978 and 1979. The high level of variability is probably due to plant moisture stress during July and August in 1978 and during September in 1979 (Table 1). Boll size for each crop increment of Paymaster 303 is shown in Fig. 4 and exemplifies the boll size variation of the other two cultivars. Boll size of the crop increments varied, but there was no seasonal pattern common to all

TABLE 5

Crop boll size characteristics for three cultivars during four growing seasons, 1977—1980, Lubbock, TX

Cultivar	Boll size (g seed cotton per boll)		Micronaire		Fiber strength (g/tex)		Fiber length (mm)	
	Mean	CV[a]	Mean	CV	Mean	CV	Mean	CV
1977								
Paymaster 303	5.35	9.0	4.6	7.4	17.8	9.8	277	4.6
Paymaster 909	6.04	8.7	5.2	9.7	17.2	7.2	245	6.2
1978								
Paymaster 303	3.89	13.2	3.7	16.3	19.1	13.7	270	6.4
Paymaster 909	4.44	15.5	4.0	7.2	19.3	12.9	247	6.3
Acala 3080	4.16	13.7	4.2	14.6	23.2	18.3	295	6.2
1979								
Paymaster 303	3.79	10.3	2.8	14.9	17.1	13.4	256	10.8
Paymaster 909	3.98	14.1	2.9	10.2	17.8	13.2	242	8.1
Acala 3080	3.96	14.3	2.9	10.5	21.0	14.9	282	8.1
1980								
Paymaster 303	4.36	8.2	5.1	6.0	25.6	9.8	244	4.5
Paymaster 909	5.28	15.3	5.0	8.5	27.2	7.3	310	3.7
Acala 3080	4.74	7.8	4.6	6.9	33.4	3.3	288	3.5

[a]CV = coefficient of variability expressed as a percentage.

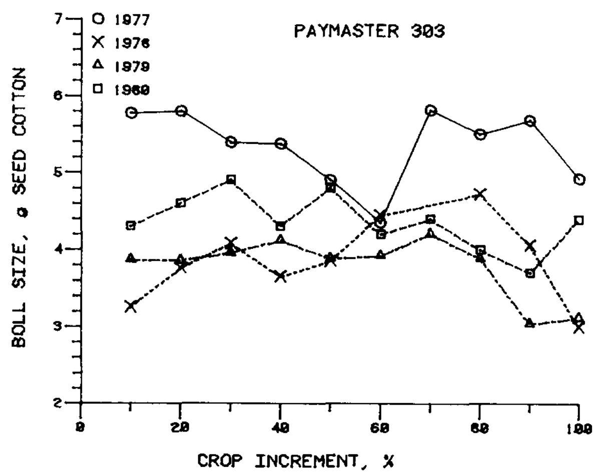

Fig. 4. Example of boll size variation between ten equal size crop increments of Paymaster 303 during 1977—1980.

years. In 1977 the 50—60% crop increment of Paymaster 303 was the end point of a trend of declining boll size that was followed by a large increase of boll size in the next crop increment. The abrupt increase in boll size is associated with an irrigation applied on July 25. The common pattern in all years was for the average of the last two crop increments of all cultivars to have smaller boll sizes than the total crop average.

Boll size, measured as the average weight of bolls in a crop increment, did fluctuate. However, when boll size was integrated over crop increments, the accumulation of number of bolls was a direct representation of yield in each year for all cultivars, as shown by the example of 1980 (Fig. 5). This result is fortunate from the standpoint of estimating crop yield progress because a given percentage of boll production represents about the same percentage of final seed cotton yield.

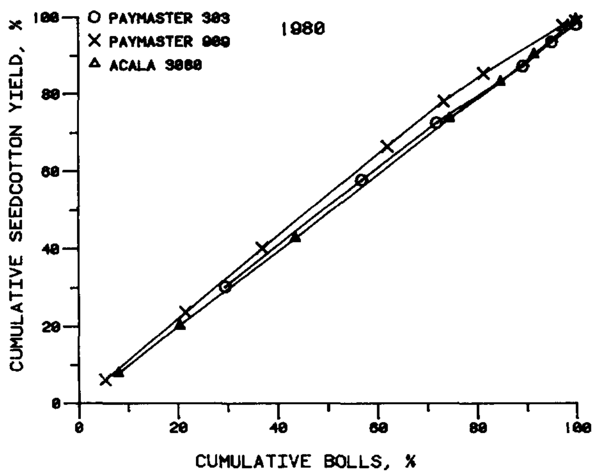

Fig. 5. Example of the direct correspondence between cumulative seedcotton yield and cumulative percentage of total bolls in 1980 for three cultivars.

Fiber quality development

The fiber properties that are most important in determining cotton lint value are grade, micronaire, fiber strength, and fiber length. Grade will not be considered here because environmental conditions after the crop has matured and processing after harvest have a large influence on grade.

Micronaire

The effect of seasonal temperatures on determining micronaire is shown by the high micronaire values in the relatively warm year of 1980 and the low micronaire values in the relatively cool year of 1979 (Table 5). Micronaire variability among crop increments was lowest in 1977 and 1980 which

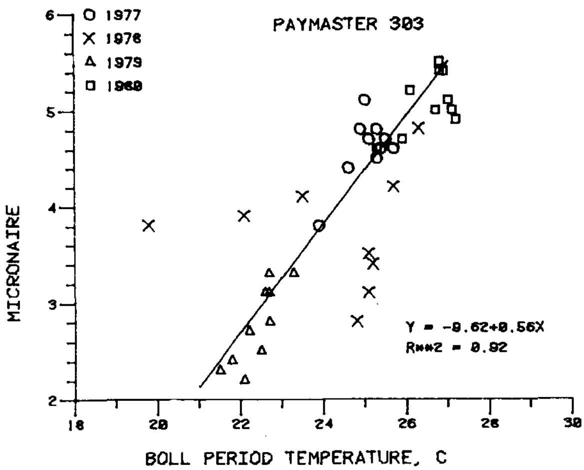

Fig. 6. Regression between boll period temperature and micronaire for Paymaster 303 in 1977, 1979, and 1980. Note the effect of plant water stress in 1978.

had warm temperatures and little plant moisture stress during the period of peak boll maturation. The importance of temperature in determining micronaire value is illustrated for Paymaster 303 in Fig. 6. Micronaire usually decreases for each successive crop increment because temperature is in a seasonal decline. The relationship between boll period temperature and micronaire of crop increments in 1978 did not fit the pattern of other years in any cultivars. Moisture stress in 1978 reduced the usually strong linear relation between temperature and micronaire as shown by the data for Paymaster 303 in Fig. 6. Apparently the direct effect of moisture stress on fibre development and its effect on slowing the rate of crop setting, which increased the time to complete the setting of the boll crop, caused limitations on the development of fiber micronaire. In years when plants were subjected to only low levels of moisture stress during fruiting (1977, 1979, and 1980), there was a good linear relationship between temperature and micronaire for all cultivars (Table 6). Moisture deficiency, in 1978 and to a smaller degree in 1980, increased the range of temperatures under which crop boll increments developed. Across all years, boll period temperature accounted for about 60% of the micronaire value of crop increments for all cultivars. While plant moisture stress did affect the rate of boll setting (Table 4), it appeared to have less influence on the relationship of temperature to micronaire. Micronaire, in Fig. 7, is normalized within cultivars to the maximum micronaire value of each cultivar during the four-year period. The 1978 data point at 22.6°C which is from Acala 3080 did not follow the pattern of other observations. Similarly, the relationship of boll period temperature and boll period of Acala 3080 crop increments in 1978 (Fig. 3) showed a different response from the other data. Solving for the maximum of the first derivative of the equation in Fig. 7 suggests that a boll temperature near 27°C is adequate for the attainment

TABLE 6

Relationship between micronaire (Y) and fiber strength (Y) with boll period temperature (X) for selected years

Cultivar	Linear regression coefficients		r^2	S.E.b
	a	b		
Micronaire[a]				
Paymaster 303	− 9.62	0.56	0.92	0.03
Paymaster 909	−11.06	0.63	0.78	0.06
Acala 3080	− 5.94	0.41	0.82	0.04
Fiber strength (g/tex)[b]				
Paymaster 303	−23.80	1.82	0.76	0.20
Paymaster 909	−30.08	2.13	0.60	0.33
Acala 3080	−33.26	2.53	0.77	0.27

[a]Micronaire equations were derived from data for the years 1977, 1979, and 1980.
[b]Fiber strength equations include data for years 1978—1980.

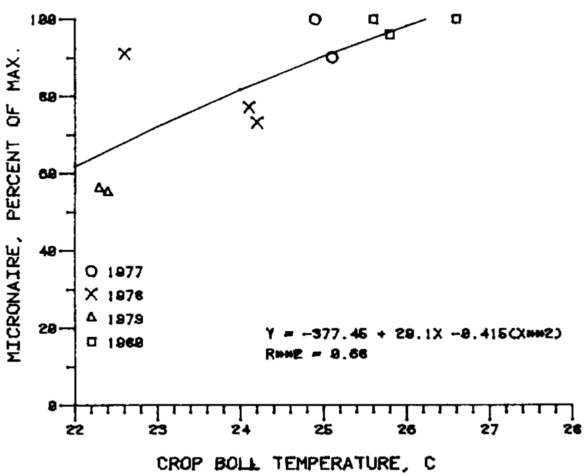

Fig. 7. Relationship between normalized micronaire values and crop boll period temperatures for three cultivars during 1977—1980.

of maximum micronaire value for the cultivars in the study. Hesketh and Low (1968) reported that maximum boll size occurred at 27°C and our findings support their results on micronaire.

Fiber strength

Fiber strength of the crop increments is also related to boll period temperature but was not greatly influenced by moisture stress in 1978 as shown by Acala 3080 (Fig. 8). The change in fiber strength had a significant linear

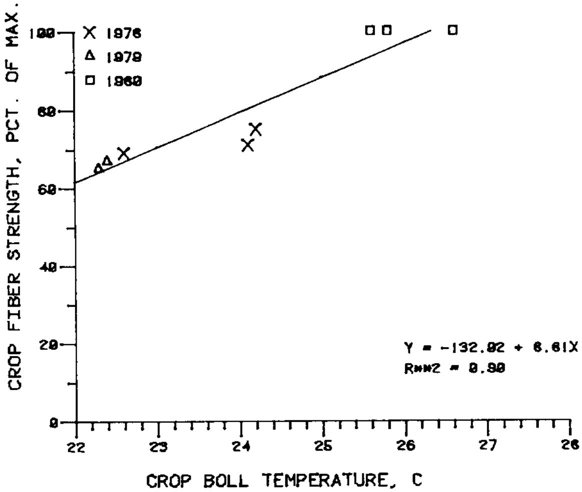

Fig. 8. Example of fiber strength relationship to boll period temperature, Acala 3080 during 1978—1980.

relationship with temperature in all cultivars. For the period 1978 through 1980, the increase in fiber strength for each degree celcius increase in temperature was 1.82, 2.13, and 2.53 g/tex for Paymaster 303, Paymaster 909, and Acala 3080 (Table 6). Acala 3080 had a significantly greater change in fiber strength with temperature than Paymaster 303. In relating boll temperature to normalized fiber strength, there was a trend of increasing strength with higher temperatures (Fig. 9). The level of variability for fiber strength and micronaire appears to be positively correlated (Table 4). This correlation is probably reflecting the influence of environment since both of these fiber properties are determined during the last half of the boll development period.

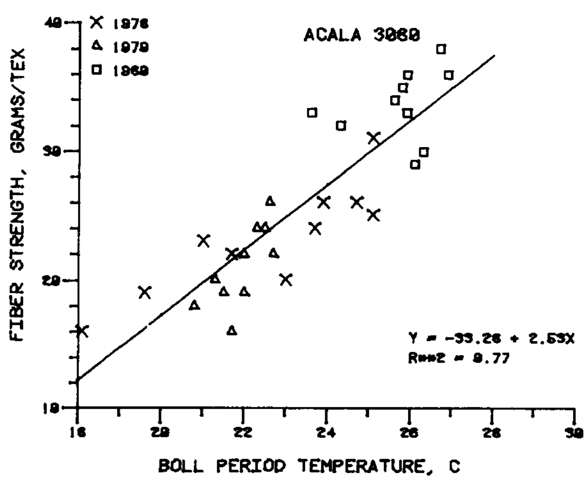

Fig. 9. Relationship between normalized fiber strength values and crop boll period temperatures for three cultivars during 1978—1980.

Fiber length

Fiber length was not related to boll period temperature or boll size in any of the cultivars. Fiber length is determined primarily during the first half of the boll development period. The variability in fiber length among crop increments was lower than for boll size, micronaire, or strength. Thus, fiber length is most strongly determined by genetics and least affected by the environment of any boll or fiber characters in Table 5.

CONCLUSIONS

Air temperature was the primary environmental variable controlling the relative rate of cotton lint accumulation, with a smaller but significant moisture stress influence for the range of conditions encountered in this study. Fiber micronaire was chiefly dependent on temperature but plant moisture stress decreased the sensitivity of micronaire to temperature. Fiber strength was strongly influenced by temperature with a significant temperature—genetic interaction. The relationships presented in this report could be helpful in defining the dynamics of crop lint yield accumulation and the development of fiber quality parameters.

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